RESEARCH DEPARTMENT

OPTICAL LINE BROADENING

Report No. T-103

(1963/13)

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1. INTRODUCTION

The line structure associated with a television picture is regarded by most observers as somewhat undesirable and several proposals have been made for the reduction or complete elimination of the line structure. These have been described in some detail in a recent report.[1] The purpose of the present note is to describe some experiments on one of the optical methods proposed in the above-mentioned report.*

The problem can be stated in terms of vertical spatial frequency. For the complete elimination of the line structure it is necessary to make the response of the picture display (including the line broadening device) zero at the fundamental and all the harmonics of the spatial frequency corresponding to the lines in one field. For example, in a 400-line interlaced raster it is necessary for the response at 200, 400, 600, etc., cycles per picture height to be zero. In the case of a 400-line sequential raster, the vertical spatial frequencies at which zeros are necessary are 400, 800, 1200, etc., cycles per picture height. In practice the slight blurring of the line raster by imperfections in optical and electron-optical systems is usually such that it is not necessary to take any special steps to ensure zero response at frequencies above 600 cycles per picture height.

One method of achieving an image which is sharp in the horizontal direction but somewhat spread out in the vertical direction is the use of an auxiliary cylindrical lens in combination with the principal (spherical) lens. With the usual circular stop, the vertical frequency/response characteristic** is of the form $2J_1(k\nu)/k\nu$ where ν is the vertical spatial frequency and k is a constant depending on the power of the cylindrical lens and the stop. The same arrangement of an astigmatic optical system but with a specially shaped aperture such as a cosine-squared one, can give a response which is zero at the fundamental vertical spatial frequency corresponding to the line structure and of fairly small magnitude at all frequencies beyond this, (see curve 6 of Fig. 10(b), reference 1). Other shapes of stop in an astigmatic optical system can give rise to responses of the type $\sin k\nu/k\nu$ or $\sin^2 k\nu/k^2\nu^2$ (curves 3 and 4 of Fig. 10(b), reference 1).

The experiments about to be described relate to one of the above variants, viz., an astigmatic optical system with a circular (or nearly circular) aperture. The purpose of the cylindrical lens is to produce a calculable amount of defocusing in one direction without affecting the definition in an orthogonal direction. The defocusing effect is equivalent to that obtained from a spherical lens when defect of focus is present and, for these experiments, the measurements and calculations were made on the basis of a defocused spherical lens.

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*Method No. 5 as listed in table, page 25.[2]

** Defined in reference 1. For brevity this expression will be abbreviated to response.

2. THE DEFOCUSED IMAGE

If the aberrations of a lens are small compared with the size of a picture element, and if diffraction can be neglected, the lens can be regarded as producing a point image from a small distant object. The effect of defocusing this image is to produce a disc of light which is of the same shape as the exit pupil. For a circular aperture the appropriate response is of the form $2J_1(k\nu)/k\nu$. This function has zeros at spatial frequencies which are not integrally related: nevertheless any prescribed spatial frequency can be arranged to be the first zero of the response function. The defocusing can be achieved by altering the plane of focus either by a physical shift of the lens (or image receiving plane) or by the use of a supplementary lens.

If the field of a lens were ideally flat (i.e., both the sagittal and tangential surfaces were in the plane orthogonal to the optical axis and passing through the paraxial focus) and the aberrations over the field were small compared with a picture element, then the spatial frequency corresponding to the first zero of $2J_1(k\nu)/k\nu$ would remain substantially constant over the field.

In terms of existing television systems and lenses the above conditions do not appear to hold. A prescribed zero can be arranged for axial imagery but the curvature of field of most lenses is such that this zero is not held over the whole field or even a substantial part of the field.

3. RESULTS

Fig. 1 shows the tangential response characteristics of the 3 in (75 mm) Speed Panchro at an aperture of f/4. The selected plane of focus is for best paraxial imagery. If a zero of $2J_1(k\nu)/k\nu$ is required at 24 cycles/mm (this is approximately the spatial frequency for 405 lines on the standard 35 mm motion picture film), then a displacement of focus of about 0·21 mm is required. Fig. 2 shows the set of tangential frequency responses which is obtained when a displacement in the plane of focus of 0·21 mm away from the lens is used. The 0 mm response has a zero at 25·8 cycles/mm. At other field positions the response varies from 0·06 up to 0·27 at this frequency of 25·8 cycles/mm. Fig. 3 shows the tangential responses when the plane of focus is taken 0·21 mm nearer to the lens. In this case, the axial zero response occurs at 23 cycles/mm. The response in the field at this spatial frequency increases up to about 0·44 at the periphery of the 35 mm field (mean of +13·6 mm and −13·6 mm responses).

The sagittal responses for a plane of focus corresponding to best paraxial imagery are shown in Fig. 4. Fig. 5 shows the effect of changing the plane of focus by 0·21 mm away from the lens. Here, the frequencies at which zero response is produced vary from 26·2 cycles/mm to 16 cycles/mm. If the plane of focus is moved 0·21 mm towards the lens (Fig. 6), the frequencies at which zero response is produced start at about 23 cycles/mm for axial imagery and increase as we go towards the periphery of the field of the lens.

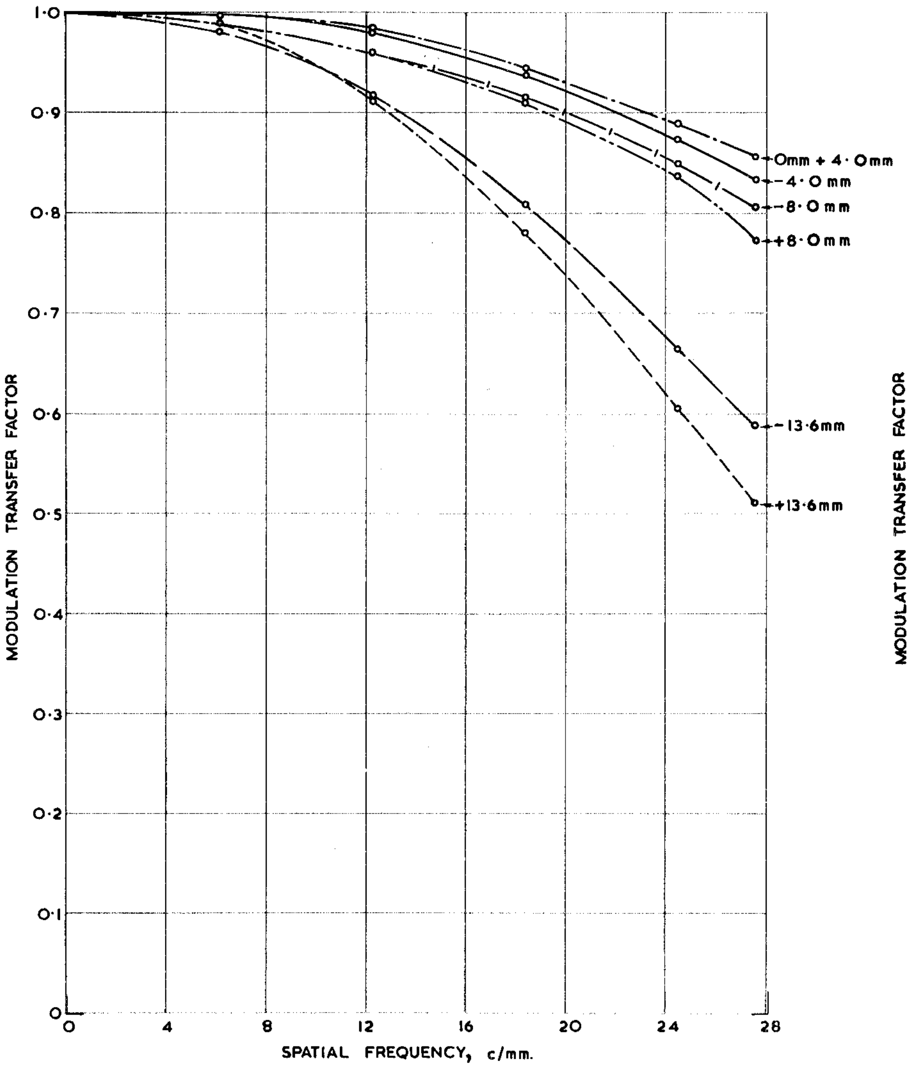

Fig. 1 - Tangential modulation transfer factors for optimum axial focus for 3 in (75 mm) Speed Panchro at f/4. Curves are shown for seven field positions with reference to the centre of the field (0 mm, ± 4 mm, ± 8 mm, ± 13·6 mm)

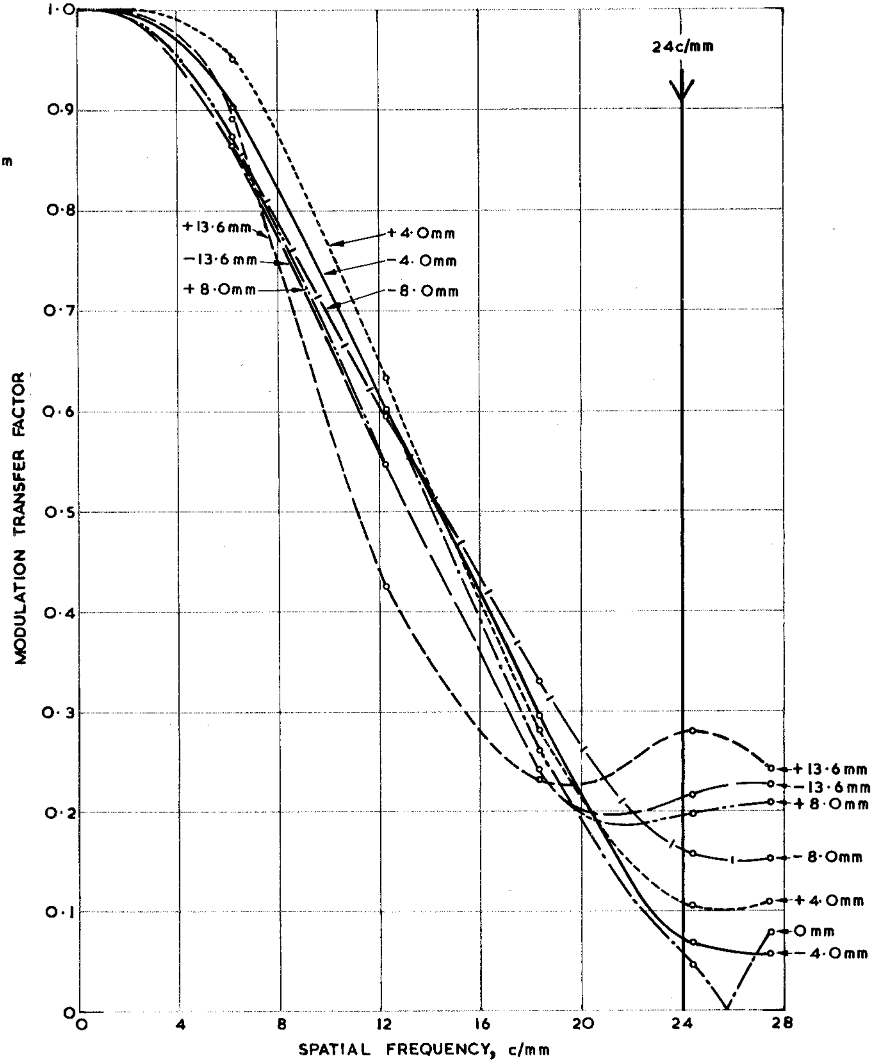

Fig. 2 - Effect of a change of focus of 0·21 mm away from the lens on the characteristics shown in Fig. 1

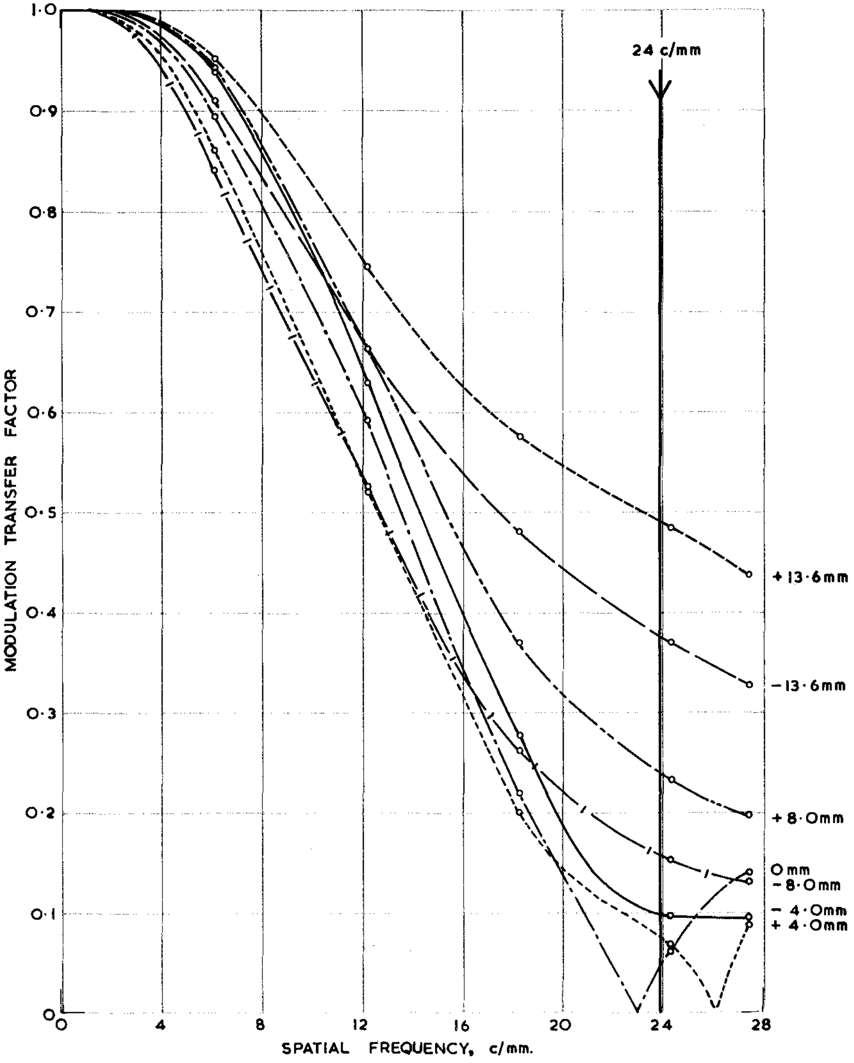

Fig. 3 - Effect of a change of focus of 0·21 mm towards the lens on the characteristics shown in Fig. 1

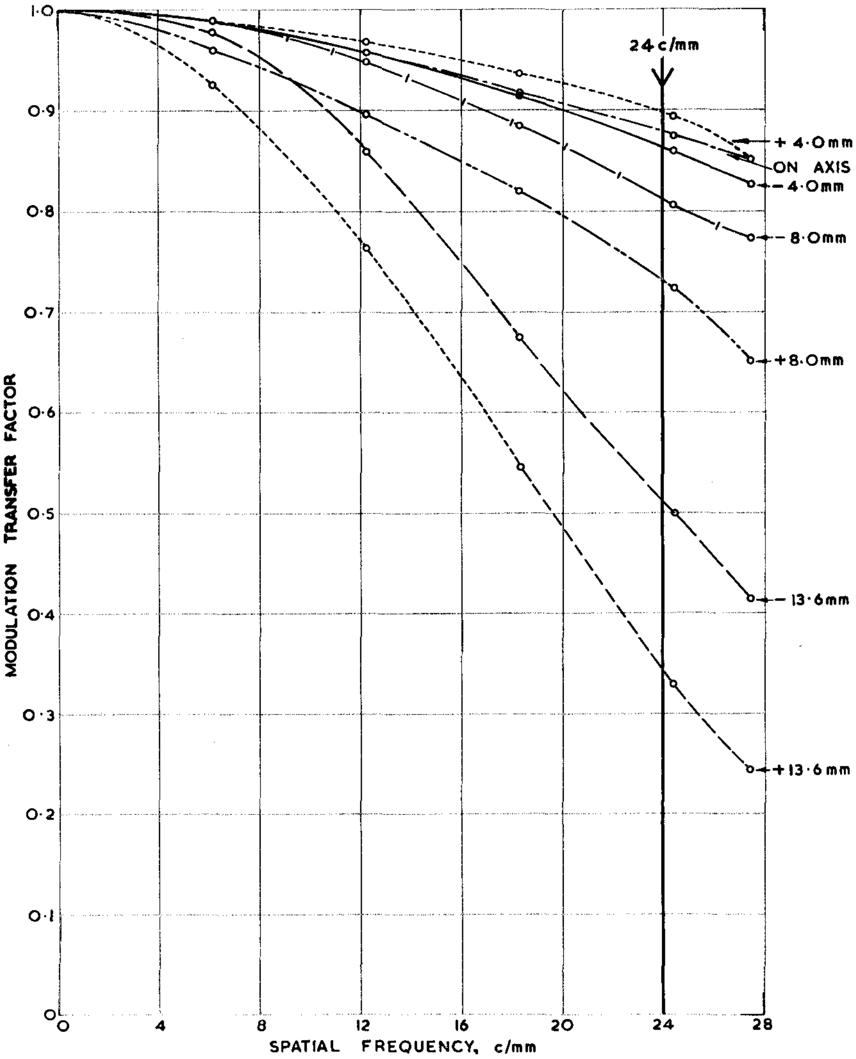

Fig. 4 - Sagittal modulation transfer factors for optimum axial focus for 3 in (75 mm) Speed Panchro at f/4

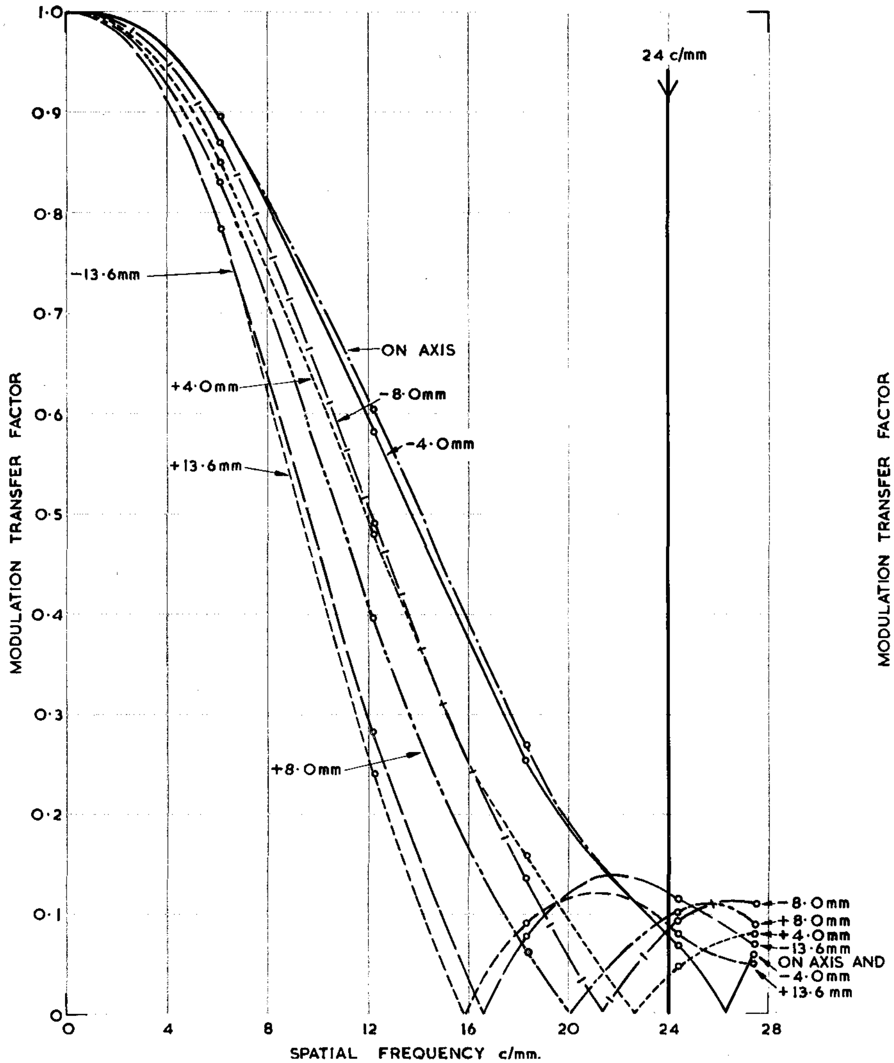

Fig. 5 - Effect of a change of focus of 0·21 mm away from the lens on the characteristics shown in Fig. 4

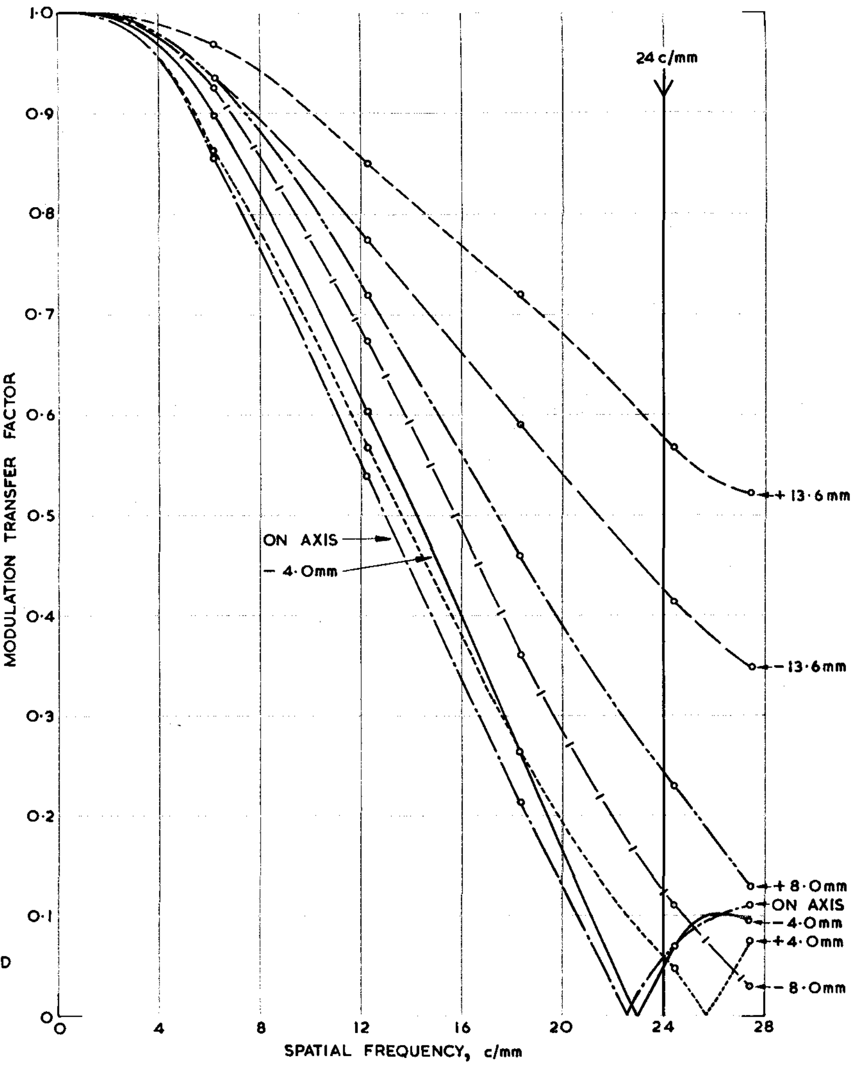

Fig. 6 - Effect of a change of focus of 0·21 mm towards the lens on the characteristics shown in Fig. 4

The variations in the spatial frequency at which zero response is achieved are due mainly (if not exclusively) to curvature of field. The sagittal and tangential surfaces of the 3 in (75 mm) Speed Panchro lens at f/4 are shown in Fig. 7. It will be observed that the displacements from the best paraxial focus are not negligible compared with the displacement of 0•21 mm. In order to verify the truth of this statement, the theoretical response curve for a defocused image (corresponding to a point image in the plane of best focus) was calculated for the cases shown in Figs. 2, 3, 5 and 6 using the information in Fig. 7 to ascertain the magnitude of the defocus distance. This simple theoretical approach should agree with the experimental results provided that the effects of geometrical aberrations are small compared with the effects of defocusing. On the whole fair agreement was found: Figs. 8 and 9 show examples in which the agreement was good and less good respectively. One effect illustrated by these examples is the filling-in of the minimum of a tangential response. This is believed to be due to coma, which produces an asymmetrical spread function, associated with a response that is not phase-linear.

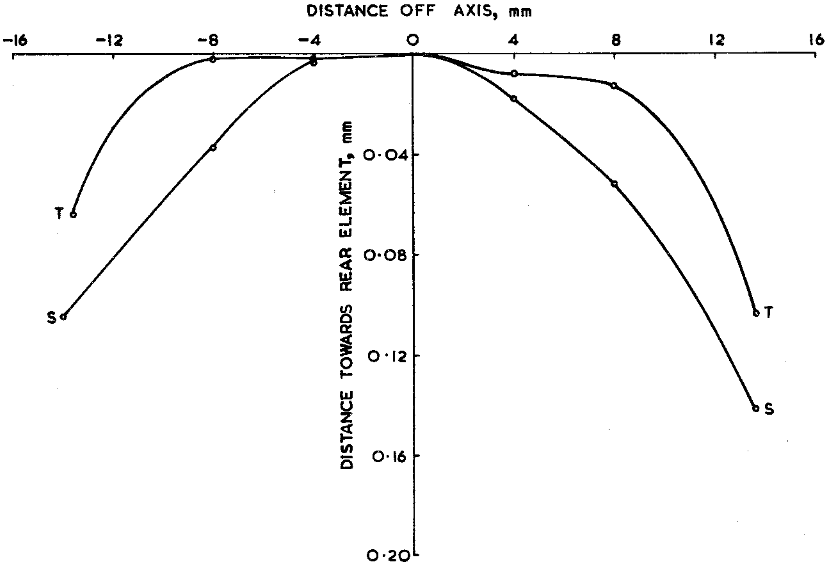

Fig. 7 - Sagittal and tangential surfaces of 3 in (75 mm) Speed Panchro at f/4

Comparing the experimental results with the calculated responses based on the simple theoretical treatment, it can be stated that in many cases the agreement was good (e.g., Fig. 8) and that in those cases where it was less good, the reason was not difficult to find. Hence it can be asserted that the lack of flatness of the image plane is primarily responsible for variation in the frequency/response characteristic (and, in particular, the spatial frequency at which zero response is obtained) over the working field of this lens.

The spatial frequency of 24 cycles/mm corresponds to the 400-line component in a 405-line television picture. It may be considered as a more important practical issue to remove the 200-line component, which corresponds to a spatial frequency of 12 cycles/mm. The defocusing distance needs to be doubled in this case: Figs. 10, 11, 12 and 13 show the results obtained with a displacement of 0•42 mm. Examination

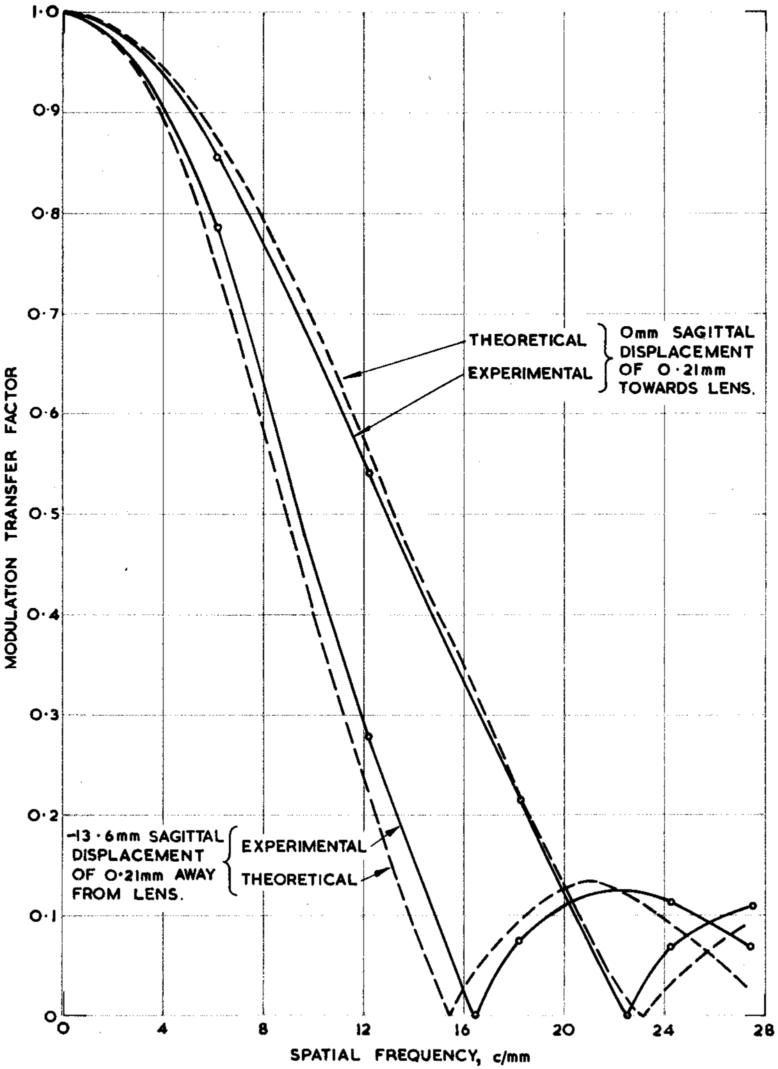

Fig. 8 - Comparison of theoretical and experimental results for two cases where agreement is good

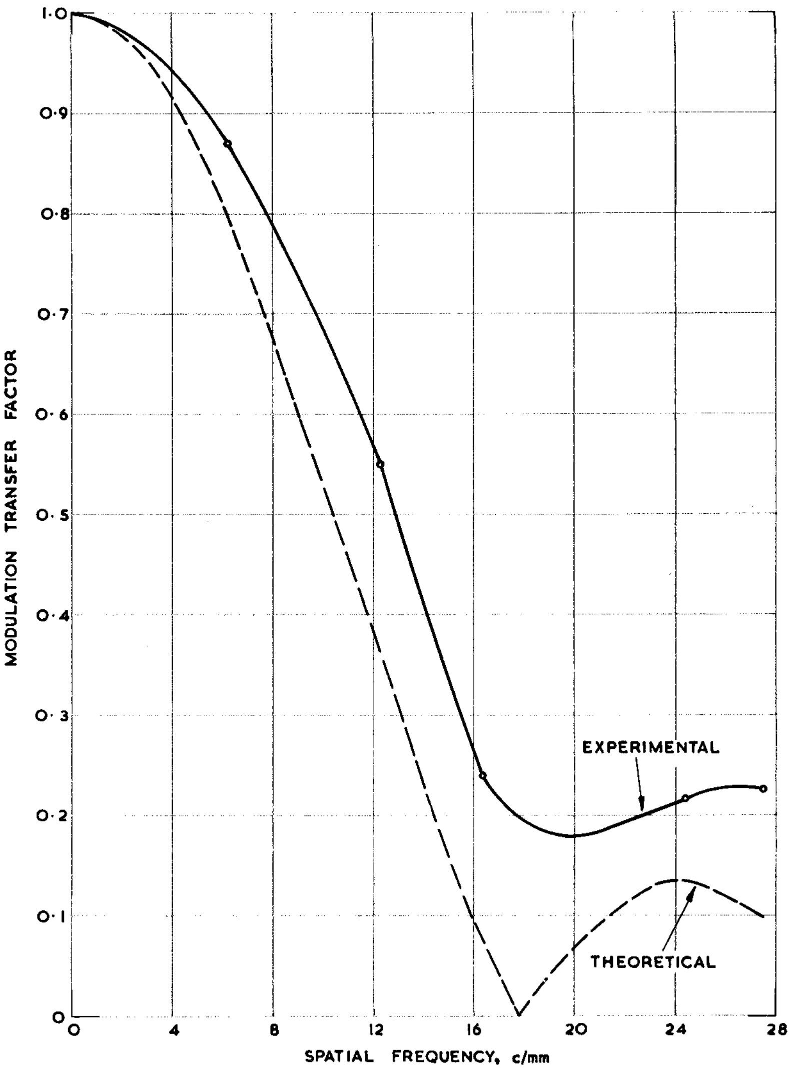

Fig. 9 - Comparison of theoretical and experimental results for a field position of -13·6 mm (tangential orientation)

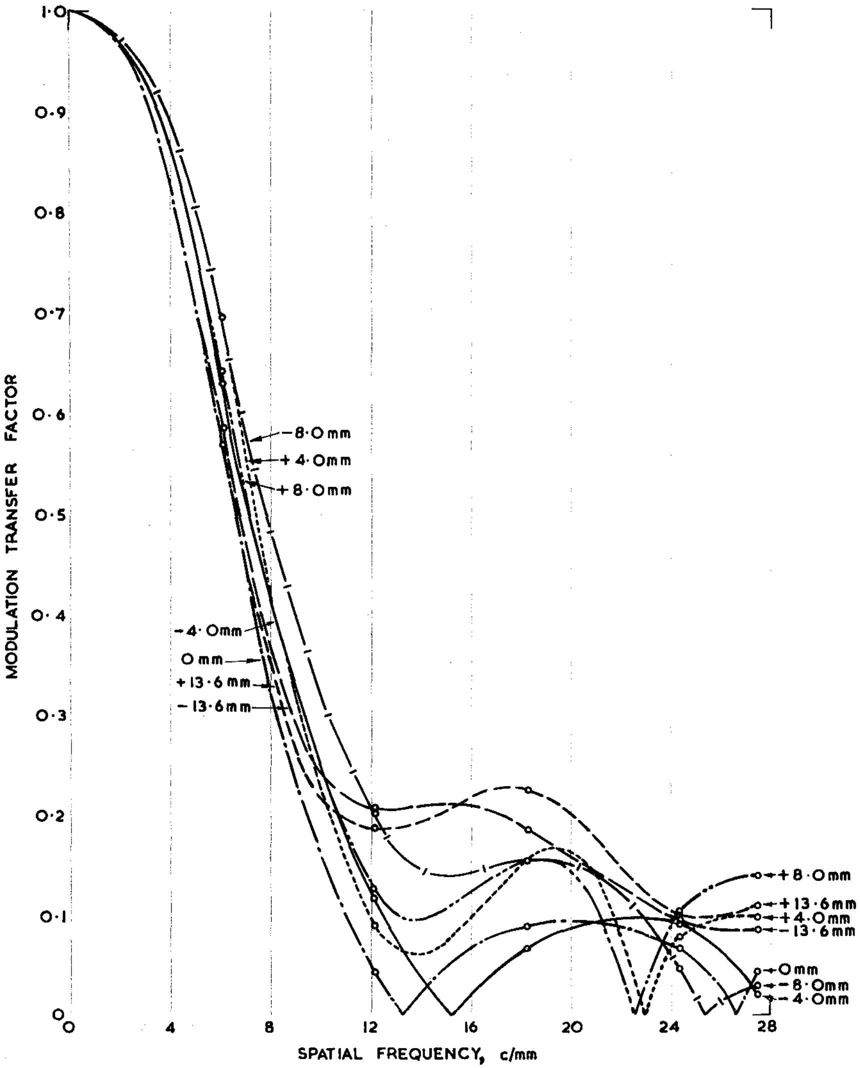

Fig. 10 - Effect of a change of focus of 0·42 mm away from the lens on the characteristics shown in Fig. 1

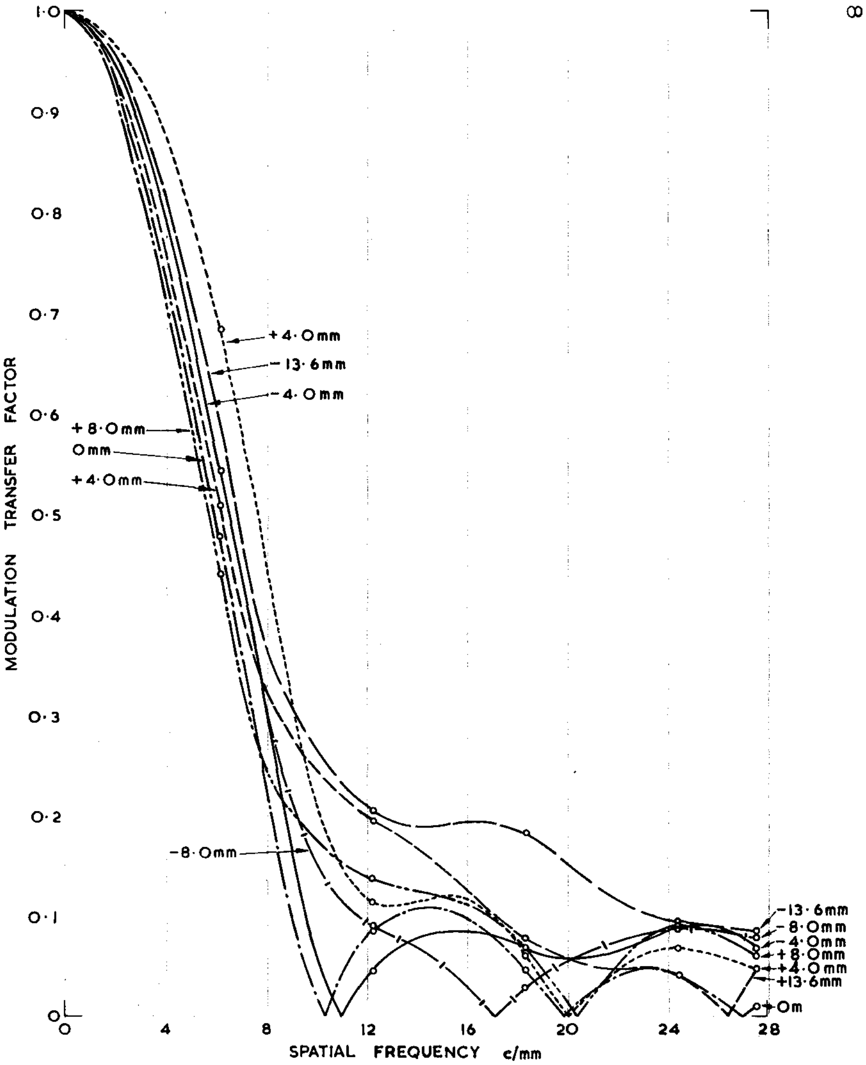

Fig. 11 - Effect of a change of focus of 0·42 mm towards the lens on the characteristics shown in Fig. 1

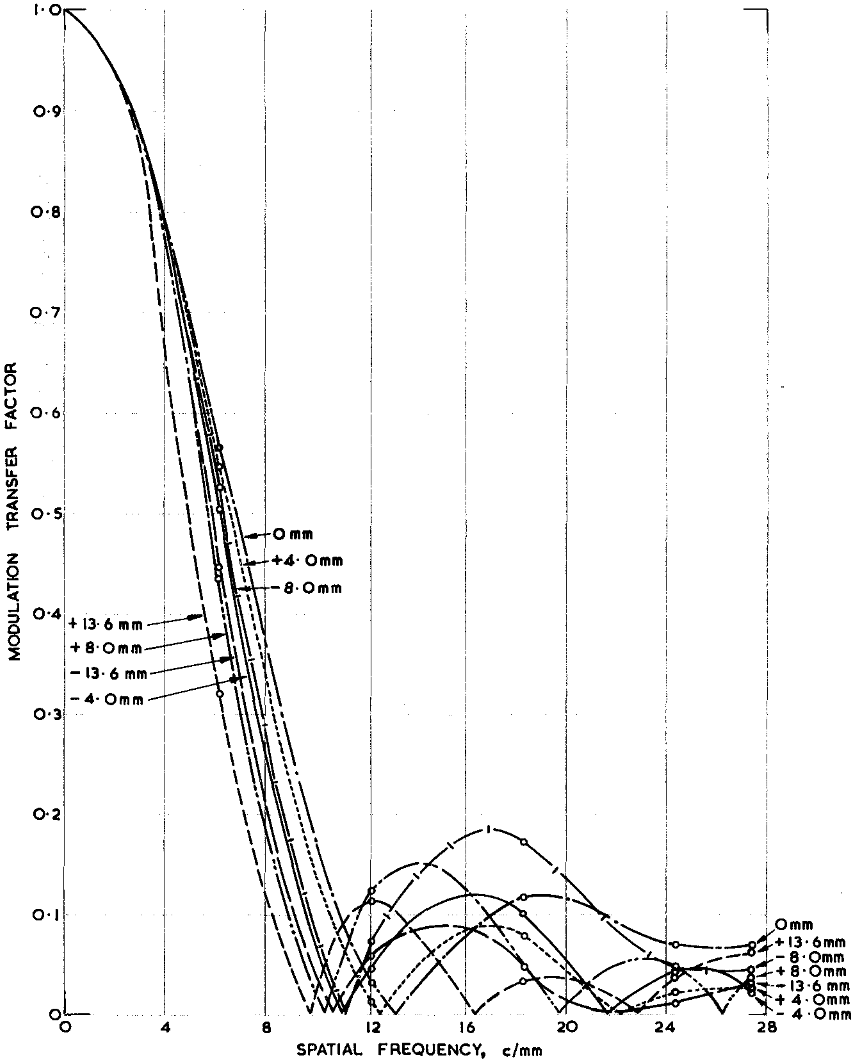

Fig. 12 - Effect of a change of focus of 0·42 mm away from the lens on the characteristics shown in Fig. 4

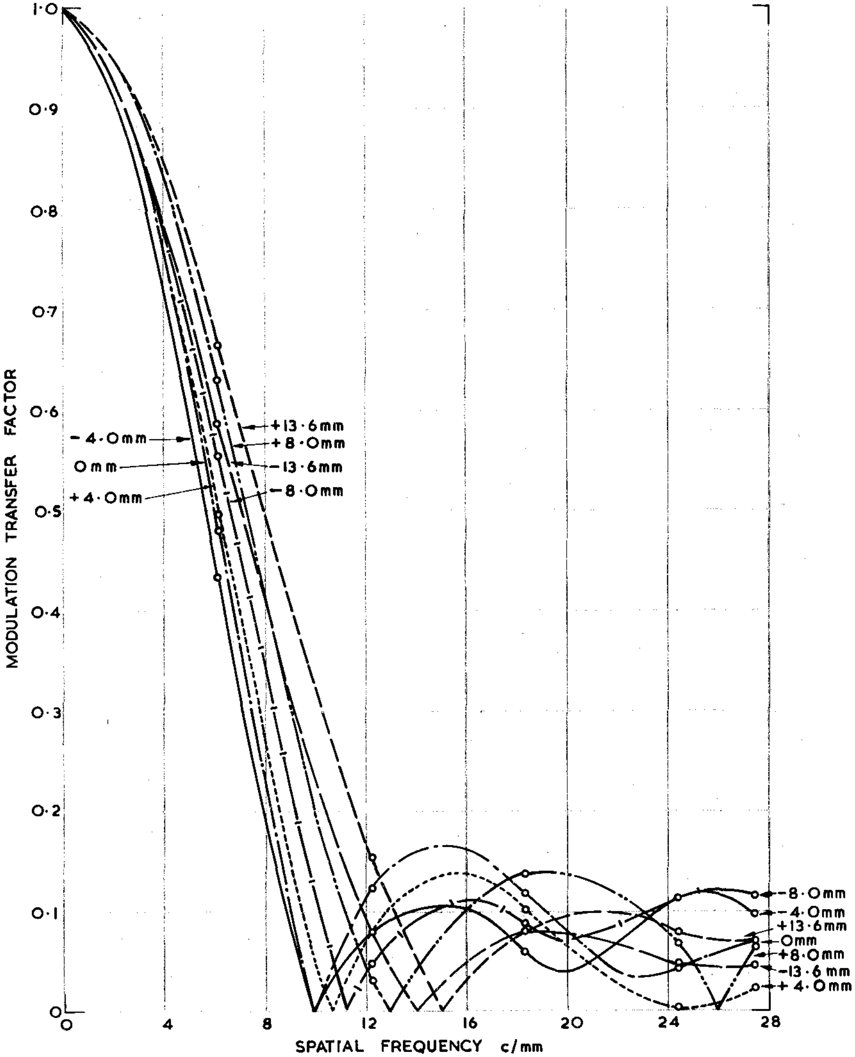

Fig. 13 - Effect of a change of focus of 0·42 mm towards the lens on the characteristics shown in Fig. 4

of these figures shows that the spatial frequency corresponding to the first zero of the spectrum is not held constant over the field. This means that it is impossible to eliminate the line structure over the whole of the field for a given and fixed setting of defocus. The response varies over the range zero to about 0·15 at a specified spatial frequency (e.g., 12 cycles/mm).

Two other lenses were investigated for their flatness of field, since it might well be that the 3 in (75 mm) Speed Panchro is unusual in this respect. Figs. 14 and 15 show the sagittal and tangential surfaces for a 2 in (51 mm) Ortal and a 3 in (75 mm) Ortal. These diagrams show that these lenses also suffer considerable curvature of field when assessed in terms of the displacement necessary to produce a zero response at 16 cycles/mm. This spatial frequency is relevant to the 400-line component in the case of the 40 mm diagonal of the photocathode of an image orthicon tube.

4. CONCLUSION

The use of a cylindrical lens to achieve line broadening is complicated by the fact that most camera lenses suffer considerable curvature of field. In consequence of this, the spatial frequency at which a zero or minimum response is obtained is subject to considerable variation over the field. Although it would be possible to reduce the visibility of the scanning lines to an extent sufficient for many

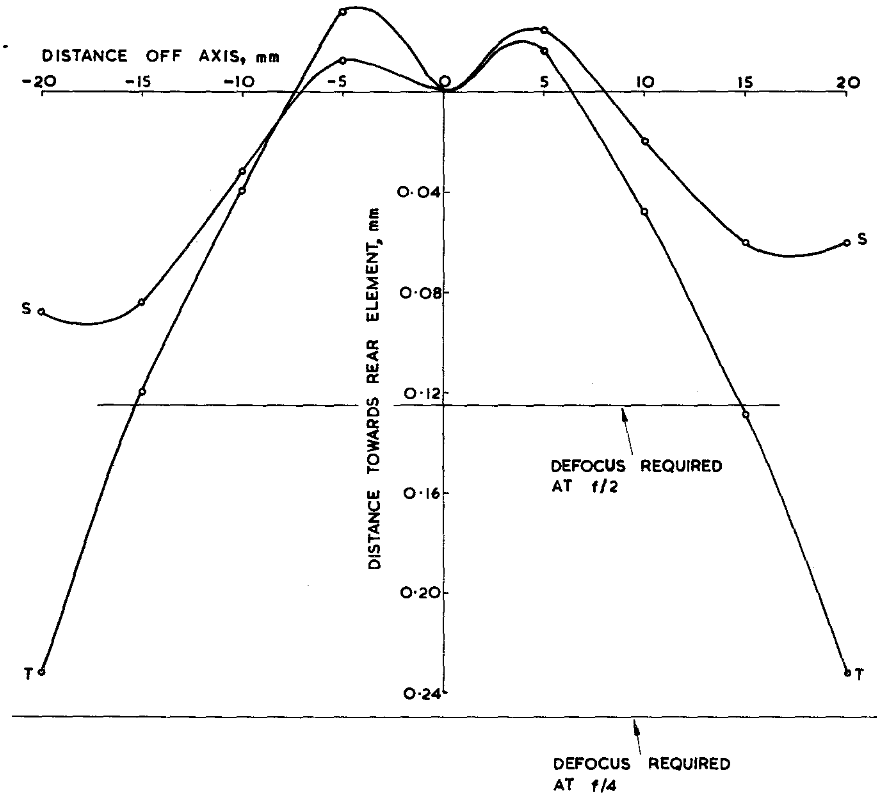

Fig. 14 - Sagittal and tangential surfaces for a 2 in (51 mm) Ortal

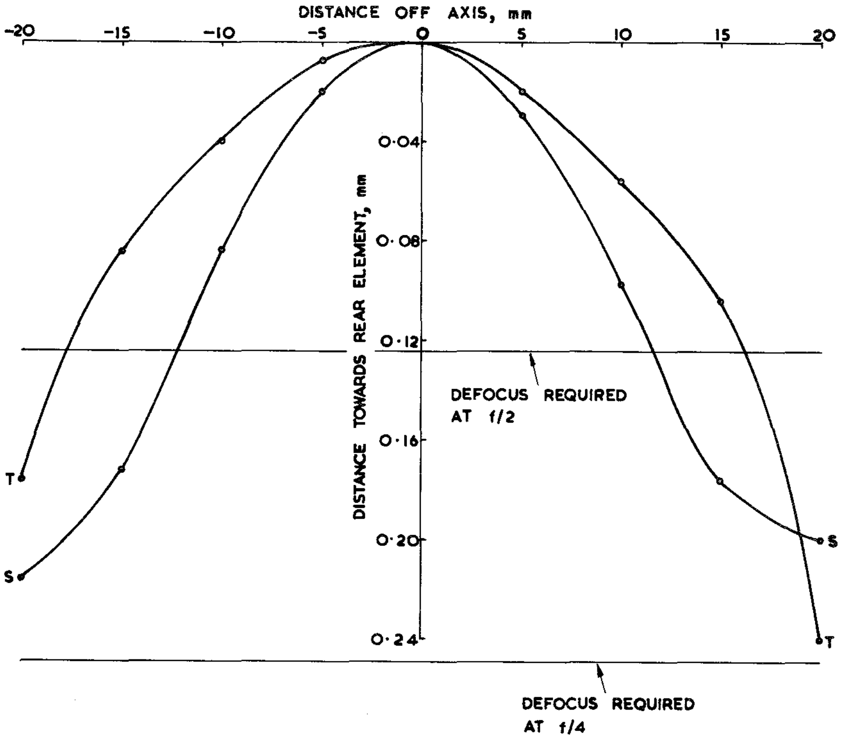

Fig. 15 - Sagittal and tangential surfaces of a 3 in (75 mm) Ortal

purposes, precise control of the line profile by this means appears difficult. For this reason the use of cylindrical lenses and specially-shaped stops appears unlikely to supplant spot wobble as a means of line broadening.

The failure of the cylindrical lens to achieve the required constant degree of defocus over the field may be explained by the fact that where an intermediate image formed by one lens forms the object for a second lens, the two-dimensional spread functions of the two lenses are not simply convolved together, unless the intermediate image is on a diffusing screen. The reason is that brightness, the independent variable in the convolution process, is equivalent to power density, not to the amplitude of any electromagnetic vector. For this reason the contributions made to the brightness of an image by light arriving via different routes combine additively only when they are not coherent.[1]

5. REFERENCES

1. "Vertical Resolution and Line Broadening," Research Department Report No. T-082, Serial No. 1962/5.

2. Patent Application No. 18729/60.

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